# THE GRANITIC ROCKS OF THE SIERRA NEVADA[1]

THE higher part of the central Sierra Nevada and nearly the entire width of the southern Sierra consist of a granular complex to most of which the name granite is ordinarily applied. In the northern and central part of the range there are likewise numerous isolated granitic areas enclosed in rocks of other kinds. The rocks of the granular complex differ greatly in age and in chemical composition. The oldest rocks represented are gneisses. Some of these are probably recrystallized sediments, but the larger portion of them may be of igneous origin. While differing in origin these gneisses are a unit in that they have all undergone a thorough recrystallization under great pressure. While the associated granites may be in part responsible for this recrystallization it cannot be ascribed to contact metamorphism alone, for areas miles in diameter are as thoroughly crystalline in their middle portions as at the granitic contact. At a future time these gneisses will be described. Some notes regarding them may be found in the Seventeenth Annual Report of the United States Geological Survey and in the text of the Big Trees folio.

The granolites[2] of the Sierra Nevada comprise nearly the entire range of granular igneous rocks. Peridotite, pyroxenite, hornblendite, gabbro, diabase, diorite, syenite, monzonite, and granite, with various intermediate types, are all represented. In this paper, however, reference will be made only to the granitic

[1] Published by permission of the Director of the U. S. Geological Survey. A large amount of information has been accumulated about the granular complex of the Sierra Nevada. It is thought better, however, to delay the publication of this material until the field work now under way is completed. There is some confusion in regard to the biotite-granite of the range and the granodiorite and quartz-monzonite. They are, therefore, more fully treated than other types of which only a brief statement is presented here.

[2] The term granolite is here used for all granular igneous rocks; thus diorite, gabbro, syenite, and granite would all be called granolite. It was first suggested by Professor L. V. Pirsson.

rocks or acid granolites, those containing free silica or quartz as an essential constituent, that is to say, in considerable amount.

Seven types of quartz-granolites have thus far been recognized. The relative age of all of them is not definitely ascertained, but so far as known it is expressed in the order in which the different types are enumerated, as follows: biotite-granite, granodiorite, quartz-monzonite, porphyritic quartz-monzonite, Bridal Veil granite, soda-granite and aplite, potash-aplite and pegmatite.

### BIOTITE-GRANITE

Biotite-granite forms very large areas in the central portion of the Sierra Nevada. It is particularly abundant in the Big Trees and Yosemite quadrangles,[1] where it has been examined most closely. The coarse biotite-granite is a rock susceptible of easy recognition in the field. Potash-feldspar is an abundant constituent, and by its conspicuous development in relatively large crystals tends to give the rock a porphyritic look. Other minerals less readily seen with the naked eye are quartz and biotite; the former in distinct grains of irregular shape, and the latter so arranged as to give a suggestion of gneissic or banded texture, even in hand specimens. Perfectly fresh specimens are secured with difficulty as the rock weathers to a considerable depth and becomes somewhat friable. Under the microscope the porphyritic texture is generally inconspicuous. The component minerals are soda-lime-feldspar (oligoclase) $>$ quartz $>$ potash-feldspar $>$ biotite $>$ titanite $>$ apatite $>$ zircon. The relative proportions of these minerals are deduced from a calculation as noted later. Chlorite is usually present as a decomposition product of the biotite, and secondary epidote may often be noted. Rutile-like needles were observed in some quartzes.

Biotite-granite usually weathers in yellowish tones, and in forms suggestive of bedding, due to a more or less well-developed gneissic structure. Indeed, at many points the biotite-granite has been greatly compressed and sheared, so that much

[1] As used by the U. S. Geological Survey a quadrangle is the area of country covered by a topographic sheet of the Atlas of the United States.

of it may be called biotite-granite-gneiss. Ilmenite was found in the granite-gneiss, but not in the more massive granite. As the granite-gneiss has, after shearing and compression, undergone recrystallization, the ilmenite may possibly be secondary. At some points the crushing, shearing and recrystallization has been so thorough that the original massive granite has been converted into a moderately fine-grained gneiss.

Analyses have been made of this granite collected at three different points. These analyses show but slight variation in composition. There is also given an average of these three analyses, and from this the molecular composition has been calculated. Analysis 164 is of a biotite-granite which is regarded by Lindgren [4] as representative of the biotite-granite of Pyramid

ANALYSES OF BIOTITE-GRANITE

| | 1452 S. N. | 1485 S. N. | 2136 S. N. | Average of Nos. 1452, 1485 and 2136 | Molecules of average | 164 Pyramid Pk. |
|---|---|---|---|---|---|---|
| $SiO_2$ | 70.43[1] | 70.75[1] | 71.08[2] | 70.75 | 1.1792 | 77.68[3] |
| $TiO_2$ | .24 | .42 | .22 | .29 | .0036 | .14 |
| $ZrO_2$ | ........ | ........ | .08 | .03 | .0002 | ........ |
| $Al_2O_3$ | 15.51 | 15.13 | 15.90 | 15.51 | .1521 | 11.81 |
| $Fe_2O_3$ | .96 | .98 | .62 | .85 | .0053 | .72 |
| FeO | 1.28 | 1.43 | 1.31 | 1.34 } | .0193 | .51 |
| MnO | trace | trace | .15 | .05 } | | trace |
| NiO | ? | none | ........ | ........ | ........ | ........ |
| CaO | 2.76 | 3.09 | 2.60 | 2.82 } | | .72 |
| SrO | .05 | .04 | .02 | .04 } | .0532 | ........ |
| BaO | .20 | .12 | .04 | .12 } | | ........ |
| MgO | .37 | .73 | .54 | .55 | .0137 | .18 |
| $K_2O$ | 5.14 | 3.62 | 4.08 | 4.28 | .0455 | 5.00 |
| $Na_2O$ | 2.75 | 3.05 | 3.54 | 3.11 | .0501 | 2.96 |
| $Li_2O$ | trace | trace | trace | trace | ........ | ........ |
| $H_2O$ below 110° C. | .08 | .10 | none | .06 | ........ | .04 |
| $H_2O$ above 110° C. | .40 | .51 | .30 | .40 | .0222 | .27 |
| $P_2O_5$ | .11 | .10 | .10 | .10 | .0007 | .10 |
| $CO_2$ | none | none | trace | ........ | ........ | ........ |
| $FeS_2$ | trace | .06 | ........ | .02 | ........ | ........ |
| $SO_3$ | ........ | ........ | none | ........ | ........ | ........ |
| Cl | ........ | ........ | .02 | .02 | .0005 | ........ |
| Total | 100.28 | 100.13 | 100.60 | 100.34 | 1.5456 | 100.13 |

Analyst: [1] Hillebrand. [2] Valentine. [3] Steiger.

[4] Am. Jour. Sci., Vol. III, 1897, p. 307.

Peak quadrangle. It will be noted, however, that the description of the rock by Lindgren indicates that it approximates in texture to a granite-porphyry, and that the chemical composition is nearer that of an aplite than of the biotite-granite to the south of the Pyramid Peak district. I myself have not observed the latter to pass into porphyritic forms with a fine-grained groundmass.

The calculation of the mineral composition is made in the following way. All of the phosphorous pentoxide ($P_2O_5$) is ascribed to apatite. All the magnesia (MgO) is ascribed to biotite. The molecular ratio of the oxides in the biotite is calculated from an analysis of biotite separated from biotite-granite No. 2136, and as the biotite in all the biotite-granite is optically similar, it is fair to assume that it has, in all three of the granites, averaged, sensibly the same composition. After deducting the titanium oxide ($TiO_2$) required for the biotite, the remaining titanium oxide is ascribed to titanite. All the zirconium oxide ($ZrO_2$) is calculated as zircon. After deducting the potash ($K_2O$) in the biotite, all the remainder is calculated as in potash-feldspar. All the soda ($Na_2O$) in the rock is supposed to be present in the albite. The chemical analysis[1] of the biotite, however, shows that it contains a little soda (0.38). In calculating the ratio of the oxides in the biotite, the soda was placed

| Composition of the biotite-granite, deduced from the average analysis above given | | Pyramid Peak, 164. Lindgren |
|---|---|---|
| | Per cent. | Per cent. |
| Quartz | 33.06 | 39.80 |
| Potash-feldspar | 20.70 | 28.17 |
| Soda-feldspar | 26.19 | 25.09 |
| Lime feldspar | 12.91 | 2.47 |
| Biotite | 5.64 | 3.10 |
| Magnetite | .69 | .61 |
| Titanite | .55 | .35 |
| Apatite | .24 | .25 |
| Zircon | .01 | ...... |
| Water | ...... | .31 |
| | 99.99 | 100.15 |

[1] Am. Jour. Sci., 1899.

with the potash. As the biotite forms only about one twentieth of the rock, the error in ignoring the soda in the biotite is small, and would not sensibly alter the result. If, however, the biotite forms a considerable part of the rock, its soda content should be separately calculated and the amount of soda in the biotite deducted from the total soda, the remainder being considered as in albite. After deducting the lime (CaO) for the apatite, titanite, and biotite, the remaining lime is calculated as in anorthite. The oxides of strontium and barium are placed with the lime. After deducting the iron-oxides ($Fe_2O_3$ and $FeO+MnO$) for the biotite, all the remaining iron oxides are calculated as in magnetite. After deducting the silica ($SiO_2$) for the titanite, biotite, and feldspar, all the remaining silica is calculated as quartz.

### GRANODIORITE

The granitoid rocks of the Sierra Nevada that were intruded at the close of Jurassic time, may be regarded as portions of one great batholith that may be supposed to underlie the entire range. The quartz-monzonites hereafter described are not regarded as belonging to the granodiorite batholith. All of the areas of this batholith are not connected at the surface, but it is more than probable that these separated areas are merely extruded tongues or gigantic apophyses of the main mass. Viewed from this standpoint, the variation of the chemical and mineral composition of this batholith is extraordinary. The rocks range from acid quartz-diorites containing over 70 per cent. of silica through quartz-mica-diorites, quartz-hornblende-diorites and quartz-pyroxene-diorites to gabbros and even olivine-gabbros. That these different rocks may be regarded as facies of one magma, appears to be indicated by the usual absence of sharp contacts and the existence of transition forms between them. The table of analyses given below probably represents very accurately the chemical variation of the rocks of the batholith. While the authors of the Gold Belt folios have always had in mind, as the typical granodiorite, a rock intermediate between granite and

diorite, in actual use the term in some of my own folios has been applied to all the rocks of which analyses are given in the table, so far as field mapping is concerned, although as a rule gabbro, even when genetically related to granodiorite proper, has been separated. Since the term has been so extensively used for quartz-diorites containing orthoclase, it is thought better to restrict the term to this usage and to call the rocks which are strictly intermediate between granite and diorite, quartz-monzonite.

While there is some doubt as to all of the areas called granodiorite in the folios being actually all portions of one magma, yet there is so great a variation within so many of these areas that the fact that the magma is a greatly variable one is established independently of the consideration of the batholith as a whole.

The evidence that the areas ascribed to this great batholith were intruded at nearly the same time is not altogether satisfactory, but at all places it points in the same direction. That is to say, wherever the granolites composing the batholith come into contact with other rocks, excepting those of post-Jurassic age, it is usually evident that they have metamorphosed those rocks, indicating that they are intrusive in them and are of later age. West of Mariposa the granodiorite has cut off and metamorphosed the Jurassic Mariposa slates into chiastolite- and mica-schists. At Mineral King, in the heart of the Sierra Nevada, to the west of Mt. Whitney, is a lens of Juratrias sediments which has been metamorphosed by granodiorite. The evidence is good that the great bulk of the pyroclastic meta-augite-andesites of the foothills are of Juratrias age. That the granodiorite is intrusive in these rocks at some points, and has metamorphosed them, is evident in the field, as for example, north and east of Mormon Bar in Mariposa county, where the meta-augite-andesite-tuffs have undergone a thorough recrystallization. In Plumas county, southeast of Sierra City, the Juratrias rocks of the Milton formation have likewise been

metamorphosed by granodiorite; also north of Genesee Valley[1] there is a quartz-gabbro which is a basic facies of the great batholith, and the adjoining Triassic slates have been metamorphosed into hornfels. There is also evidence that the rocks of this batholith are later in age than the serpentines and associated magnesian rocks. This is particularly evident in the Bidwell Bar quadrangle, where the rocks of the magnesian series are cut by dikes of granodiorite, and in general throughout this quadrangle the rocks surrounding the granodiorite areas, whether of sedimentary or of igneous origin, show contact metamorphism. However, in the Bidwell Bar quadrangle the age of the sedimentary rocks, so far as known, is Carboniferous, and it can therefore only be said that in this region the granodiorite is post-Carboniferous.

In a paper[2] published in 1893, Lindgren describes typical granodiorite as follows: "The rock consists in typical development of feldspar, quartz, biotite, and hornblende with medium-grained hypidiomorphic structure. The soda-lime-feldspars are usually considerably and to a variable extent in excess of the alkali-feldspars. The silica varies between 60 and 73 per cent.; the amount of lime is variable, but it rarely exceeds, while it usually falls somewhat short of, the sum of the alkalies. While in some varieties which cannot be distinguished from the others in the field, there is more potash than soda, a frequently occurring relation is 2 per cent. $Ka_2O$ to 4 per cent. $Na_2O$. It will be seen that the rock very closely approaches some quartz-mica-diorites and often might be indicated by that name."

In his later paper on the gold quartz veins of Nevada City and Grass Valley, published in the Seventeenth Annual Report of the U. S. Geological Survey, Lindgren gives the limits of chemical variation and average composition of granodiorite as follows.

[1] DILLER, Bull. 150 U. S. Geol. Surv., p. 338.

[2] The Auriferous Veins of Meadow Lake, California. Am. Jour. Sci., Vol. XLVI, 1893, pp. 202, 203.

In his investigation of Pyramid Peak quadrangle, Lindgren found large areas of granitic rocks containing amphibole and biotite and resembling granodiorite in a general way. Some of these rocks are somewhat basic and probably correspond to the granodiorite of the Gold Belt region in chemical composition; but other areas contain more alkali and less lime than the typical granodiorite of this paper. Lindgren, however, concluded that this alkali-rich rock should be called the typical granodiorite, inasmuch as it occurs in very large areas, and also since it occupies a place almost exactly intermediate between quartz-diorite and granite. Since that time much field work has been done in the south central Sierra Nevada where the granular complex is finely exposed, most of the soil and loose rock having been removed by the glaciers that formerly covered the region. The opportunities, therefore, of studying the relations of the granites in this section are unexcelled. The different granitic rocks resemble one another so much in general aspect that the contacts between different kinds are sometimes discovered only after careful search. As a rule a person will pass from one kind of granite to another without having observed any change in the rock until the difference is called to his attention by some striking feature. It is not to be wondered

LIMITS OF VARIATION AND AVERAGE COMPOSITION OF GRANODIORITE

| | Limits of variation | Average composition |
|---|---|---|
| | Per cent. | Per cent. |
| $SiO_2$ | 59 to 68½ | 65 |
| $Al_2O_3$ | 14 to 17 | 16 |
| $Fe_2O_3$ | 1½ to 2¼ | 1.50 |
| $FeO$ | 1½ to 4½ | 3 |
| $CaO$ | 3 to 6½ | 5 |
| $MgO$ | 1 to 2½[1] | 2 |
| $K_2O$ | 1[2] to 3½ | 2.25 |
| $Na_2O$ | 2½ to 4½ | 3.50 |
| Remainder | ............ | 1.75 |
| | | 100 |

[1] Three and one half in one analysis.

[2] Certain masses in the foothills go below 1 per cent.

at, therefore, that the relations of the different granites is not yet clearly understood. The exposures at a number of points clearly show that the granodiorite proper is intrusive in, and therefore younger than, the biotite-granite. Other exposures near Yosemite Valley show a sharp contact between the rock here called quartz-monzonite and granodiorite proper. While the evidence of these two rocks being distinct is not altogether satisfactory at present, it is probable that the quartz-monzonite is later in age than the granodiorite. In order to show the chemical relations of granodiorite to related rocks, some partial analyses are here given:

| | | Granodiorite series | | Quartz-monzonite | | 103 Pyramid Peak |
|---|---|---|---|---|---|---|
| | Tonalite | Quartz-diorite | Granodiorite | Banatite | Adamellite | |
| Silica | 66.91 | 57.74 | 65.48 | 64.39 | 68.39 | 67.45 |
| Alumina | 15.20 | 17.36 | 16.05 | 15.90 | 13.47 | 15.51 |
| Lime | 3.73 | 6.81 | 4.88 | 4.15 | 3.24 | 3.60 |
| Magnesia | 2.35 | 3.62 | 2.13 | 1.93 | 1.02 | 1.10 |
| Potash | .86 | 2.01 | 2.43 | 3.57 | 3.28 | 3.66 |
| Soda | 3.33 | 3.07 | 3.49 | 3.48 | 3.85 | 3.47 |

The rock described by vom Rath and called tonalite, has sometimes been regarded as a synonym for granodiorite. That such is not the case, however, will appear from the analysis given above. If this analysis is reliable it is clear that tonalite is a typical quartz-diorite unusually rich in silica. The analysis of the tonalite is the mean of two analyses by Kenngott.[1] The specimen analyzed came from Avio See and vom Rath,[2] who originated the name, analyzed the plagioclase of the tonalite of Adamello, and found the feldspar to be basic andesine

The quartz-diorite analysis may be regarded as a fair average of the smaller granodiorite areas noted in the Gold Belt folios and of the marginal portions of larger areas. This analysis is the mean of five basic quartz-diorite analyses given in the large table of granodiorite analyses.

[1] Zeit. Geol. Ges., Vol. XVII, 1865, p. 572.

[2] Zeit. Geol. Ges., Vol. XVI, 1864, p. 249.

ANALYSES OF ROCKS FROM THE POST-JURASSIC GRANODIORITE BATHOLITH OF THE SIERRA NEVADA

| | Olivine gabbro | Basic quartz-diorites | | | | | Granodiorites proper | | | | | Acid quartz-diorites | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. 941 S. N.[1] | No. 1495 S. N.[2] | No. 225 S. N.[2] | No. 936 S. N.[2] | No. 851 S. N.[3] | No. 691 S. N.[1] | No. 369 S. N.[2] | No. 17 S. N.[2] | Grass Valley[2] | Nevada City[2] | No. 71 S. N.[2] | No. 303 S. N.[2] | No. 22 S. N.[2] |
| $SiO_2$ | 43.41 | 55.86 | 57.26 | 57.80 | 58.09 | 59.68 | 62.62 | 63.43 | 63.85 | 66.65 | 67.33 | 68.65 | 70.36 |
| $TiO_2$ | .39 | 1.20 | .53 | .70 | .95 | .65 | .55 | .73 | .58 | .38 | .36 | .28 | .20 |
| $Al_2O_3$ | 23.15 | 19.30 | 16.51 | 16.43 | 17.46 | 17.09 | 17.51 | 14.20 | 15.84 | 16.15 | 15.93 | 16.34 | 15.47 |
| $Cr_2O_3$ | none | .... | none | none | .... | none | .... | .... | .... | .... | .... | .... | .... |
| $Fe_2O_3$ | 3.72 | .91 | 3.27 | 1.62 | 1.12 | 2.85 | .49 | 1.54 | 1.91 | 1.52 | 1.90 | .93 | .98 |
| $FeO$ | 4.39 | 4.78 | 5.19 | 6.51 | 5.08 | 2.75 | 4.06 | 4.56 | 2.75 | 2.36 | 1.59 | 1.48 | 1.17 |
| $MnO$ | .08 | .16 | .18 | .18 | none | trace | .05 | .03 | .07 | .10 | .09 | .08 | trace |
| $NiO$ | none | trace | trace? | .03 | .... | none | .... | .... | .... | .... | .... | .... | .... |
| $CaO$ | 14.27 | 7.31 | 6.69 | 7.21 | 6.24 | 6.62 | 5.49 | 5.51 | 4.76 | 4.53 | 4.09 | 3.07 | 3.18 |
| $SrO$ | none | .04 | .06 | trace? | .04 | trace | trace | trace | trace | trace | trace | .07 | trace |
| $BaO$ | none | .13 | .10 | .09 | .07 | .04 | trace | .06 | .06 | .07 | .08 | .09 | .06 |
| $MgO$ | 7.65 | 2.94 | 3.41 | 4.14 | 4.06 | 3.54 | 2.84 | 2.35 | 2.07 | 1.74 | 1.63 | 1.29 | .87 |
| $K_2O$ | .22 | 1.52 | 2.93 | 2.29 | 2.02 | 1.31 | 1.76 | 2.19 | 3.08 | 2.65 | 2.46 | 1.85 | 1.71 |
| $Na_2O$ | .82 | 3.52 | 2.65 | 2.35 | 2.94 | 3.87 | 3.49 | 3.49 | 3.29 | 3.40 | 3.76 | 4.85 | 4.91 |
| $Li_2O$ | trace | trace | trace | trace | none | trace | trace | none | trace | trace | trace | trace | trace |
| $H_2O$ below 110° C. | .18 | .19 | .20 | .11 | .29 | .15 | .22 | .15 | .28 | .18 | .19 | .24 | .06 |
| $H_2O$ above 110° C. | 1.53 | 1.23 | .95 | .38 | 1.45 | 1.00 | .92 | 1.50 | 1.65 | .72 | .66 | .62 | 1.00 |
| $P_2O_5$ | .02 | .38 | .30 | .19 | .17 | .25 | .12 | .11 | .13 | .10 | .11 | .15 | .11 |
| $CO_2$ | .10 | none | none | none | .21 | .20 | .... | .... | .... | .... | .... | .... | .... |
| $FeS_2$ | .14 | .39 | none | none | c. .11 | none | .... | .... | .04 | .02 | .... | .... | .... |
| $SO_3$ | .... | .... | .... | .... | .05 | trace | .... | .... | .... | .... | .... | .... | .... |
| Cl. | trace | .... | .... | .... | .02 | .03 | .... | .... | .... | .... | .... | .... | .... |
| F. | .... | .... | .... | .... | trace | none | .... | .... | .... | .... | .... | .... | .... |
| Total | 100.09 | 99.86 | 100.23 | 100.03 | 100.37 | 100.03 | 100.12 | 99.85 | 100.36 | 100.57 | 100.18 | 99.99 | 100.08 |

Analyst: [1] Stokes, [2] Hillebrand, [3] Steiger.

The granodiorite analysis may be regarded as typical of that rock and as representing the average rock of many areas. The analysis is the mean of the five analyses given in the large table. A comparison with the banatite analysis indicates a close relationship, but a granodiorite very seldom attains so high an alkali content as that of a banatite. The banatite analysis is a mean of five analyses by Brögger.[1] The analysis of the adamellite is a mean of six analyses by Brögger.[2] The quartz-monzonite analysis 103 Pyramid Peak is Lindgren's typical granodiorite of his latest paper.[3] It is clear that this rock would be placed with the monzonites by Brögger.

Granodiorite when typical is composed of plagioclase (oligoclase-andesine, but usually andesine) > quartz > orthoclase. Biotite and green aluminous amphibole are abundant constituents, but are variable in their relative amounts, and at times only one of these ferro-magnesian elements is present. Magnetite, titanite, and apatite are nearly always present as accessories. The rock is usually evenly granular in texture and of a light gray color.

### QUARTZ-MONZONITE

As has already been stated under granodiorite, there are very large areas of a rock containing amphibole and biotite which resembles granodiorite and perhaps may be related to it genetically. From the analyses given below it will be seen, however, that the rock is richer in alkali and poorer in lime than the most acid of the granodiorites of the Gold Belt. This rock forms part of the east wall of Yosemite Valley and Half Dome, North Dome, Starr King, and other points. In general it is quite massive and thus lends itself to a method of weathering called exfoliation, which ordinarily results in the production of dome-like forms. It is composed of oligoclase > quartz > orthoclase > biotite > amphibole. There are present as accessories titanite, apatite, iron ore, and zircon. It thus strongly resembles grano-

[1] Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo, p. 62.

[2] *Ibid.*, p. 62.

[3] Am. Jour. Sci., 1897.

ANALYSES OF GRANITIC ROCKS

| | Quartz-monzonite | | | Porphyritic quartz-monzonite | Soda-granite and aplite | | | Quartz-diorite aplite | Quartz-diorite |
|---|---|---|---|---|---|---|---|---|---|
| | No. 2179 S. N. | No. 1751 S. N. | No. 103 Pyramid Peak | No. 39 S. N. | No. 399 S. N. | No. 413 S. N. | No. 725 S. N. | No. 1490 S. N. | No. 1495 S. N. |
| $SiO_2$ | 66.83 | 66.91 | 67.45 | 66.28 | 73.18 | 74.21 | 76.00 | 69.66 | 55.86 |
| $TiO_2$ | .54 | | .58 | .54 | .25 | .30 | .04 | .21 | 1.20 |
| $ZrO_2$ | .04 | | | | | | | | |
| $Al_2O_3$ | 15.24 | | 15.51 | 16.03 | 13.66 | 14.47 | 14.88 | 17.57 | 19.30 |
| $V_2O_3$ | | .01[1] | | | | | | | |
| $Fe_2O_3$ | 2.73 | | 1.76 | 1.80 | .21 | .35 | .65 | .21 | .91 |
| FeO | 1.66 | | 2.21 | 1.88 | 2.24 | .50 | .10 | 1.04 | 4.78 |
| MnO | .10 | | | .05 | .07 | none | trace | trace | .16 |
| NiO | | | | | | | none | none | trace |
| CaO | 3.59 | 3.51 | 3.60 | 3.75 | 2.10 | 1.71 | .19 | 4.54 | 7.31 |
| SrO | .03 | | | trace | trace | trace | none | .05 | .04 |
| BaO | .11 | | | .08 | .10 | none | trace | .03 | .13 |
| MgO | 1.63 | | 1.10 | 1.12 | .93 | .28 | .06 | .58 | 2.94 |
| $K_2O$ | 4.46 | 3.13 | 3.66 | 3.49 | 2.72 | .10 | 2.77 | .71 | 1.52 |
| $Na_2O$ | 3.10 | 3.59 | 3.47 | 4.10 | 3.70 | 7.62 | 3.52 | 4.91 | 3.52 |
| $Li_2O$ | trace | trace | | trace | trace | trace | none | none | trace |
| $H_2O$ below 110° C. | none | | .14 | .11 | .10 | .15 | .20 | .05 | .19 |
| $H_2O$ above 110° C. | .56 | | .63 | .39 | .57 | .23 | 1.42 | .50 | 1.23 |
| $P_2O_5$ | .18 | | .12 | .30 | .09 | .07 | .11 | .03 | .38 |
| $CO_2$ | trace | | | | .17 | | none | none | none |
| $FeS_2$ | | | | | | | | trace | .39 |
| $SO_3$ | none | | | | | | | | |
| Cl | .02 | | | | | | | | |
| F | | | | | | | | | |
| Total | 100.82 | | 100.25 | 99.92 | 100.09 | 99.99 | 99.94 | 100.09 | 99.86 |
| Analyst | Valentine | Stokes | Steiger | Hillebrand | Hillebrand | Hillebrand | Stokes | Hillebrand S = trace | Hillebrand S = 0.21 |

[1] The $V_2O_3$ det. by Hillebrand.

diorite in mineral composition. One of the chief differences is the more acid character of the plagioclase which is, so far as known, always oligoclase. It also contains zircon, which is not usually found, and certainly is not abundant, in granodiorite. It is probably, moreover, of later age. The quartz-monzonite of the Sierra Nevada would be called a hornblende-biotite-granite by Rosenbusch. The three analyses given in the table below indicate that the chemical composition of this rock is remarkably uniform. The quartz-monzonite of the east wall of Yosemite Valley appears to be in sharp contact with the granodiorite mass that lies immediately west. At any rate the transition from the even-grained monzonite with scattered amphiboles to the more basic granodiorite, occurs within a very few feet at a number of points. More investigation, however, is needed.

The adoption of the term quartz-monzonite instead of granodiorite will perhaps be objected to by some petrographers on the ground that granodiorite is the older term. As has been shown, however, the latter rock does not occupy a strictly intermediate position between granite and quartz-diorite unless we extend the range of its chemical variation so as to include the quartz-monzonite of the higher parts of the Sierra. If we should confine the term quartz-monzonite, or granite-diorite, to quartz-feldspar rocks in which the potash and soda-lime feldspar are present in about equal amount, as Brögger has done, we would then have to exclude from this type nearly all of the rocks called granodiorite (quartz-orthoclase-diorite) in the Gold Belt folios. It would, therefore, seem better to let the term granodiorite stand for the rocks for which it has been used, and use one of the perfectly definite terms quartz-monzonite or granite-diorite for the rocks intermediate between granite and quartz-diorite. The term monzonite has already been adopted by the United States Geological Survey for folio use, and it seems, therefore, desirable for the members of the survey likewise to use the term quartz-monzonite for monzonites containing abundant quartz, in the same way that we use quartz-diorite for diorites containing abundant quartz.

THE PORPHYRITIC QUARTZ-MONZONITE[1]

Forming large areas along the higher parts of the range is a coarse granitic rock containing numerous porphyritic orthoclases which are often more than two inches in length. This rock is in sharp contact with the quartz-monzonite, above described, to the northwest of Lake Tenaya in the Yosemite Park, and doubtless at other points. While not differing much in chemical composition (see No. 39, table of analyses) from the latter rock, its marked porphyritic character and the usual absence of amphibole readily distinguish it. Along the contact, however, the porphyritic quartz-monzonite sometimes contains abundant amphibole. The orthoclase phenocrysts are evidently formed at a late period in the consolidation of the rock, for these contain as inclusions most of the minerals of the groundmass, including plagioclase, biotite, quartz, titanite, and iron oxide. The inclusions have no definite arrangement in the phenocrysts.

BRIDAL VEIL GRANITE

In the drainage of Bridal Veil Creek, on Horse Ridge, and at many other points in the Yosemite Park, there are considerable masses of a white, rather fine-grained granite which has been designated Bridal Veil granite. It often shows an orbicular structure, there being a central white nucleus composed of quartz and feldspar, surrounded by a layer rich in biotite. This granite is intrusive in the biotite granite and often contains near the contact chunks of the latter. It also incloses fragments of dioritic rocks, which are likewise found as nodules and small areas in

ANALYSES OF BRIDAL VEIL GRANITE

| | No. 2558 S. N. | No. 2051 S. N. |
|---|---|---|
| $SiO_2$ | 71.45 | 69.81 |
| CaO | 2.40 | 2.31 |
| $K_2O$ | 3.25 | 5.25 |
| $N_2O$ | 3.53 | 2.79 |

[1] Fourteenth Ann. Rep. U. S. Geol. Surv., pp. 478–480.

some of the other granites. No complete analysis has been made of this granite, but there are given above two partial analyses which indicate some variation in chemical composition if they are in reality both from the same magma.

No. 2558 is from north Cathedral Rock in Yosemite Valley, and No. 2051 is from a dike in the bed of the Middle Tuolumne River, about 4.5 kilometers northeast of Bald Mountain. Both analyses were made by Dr. H. N. Stokes.

### SODA-GRANITE AND APLITE

Granitic rocks rich in soda are not abundant in the Sierra Nevada. The largest mass known lies east of Cathay Valley in Mariposa county. This area is clearly later than the diabase that is found to the west. Along the contact in and southeast of Cathay Valley a contact-breccia has been formed which is a mile or more in width. This is composed of fragments of the diabase cemented by the soda-granite. On the northeast the aplite area is in contact with the slates of the Mariposa formation. These slates are flinty near the contact on Agua Fria Creek, where also they are of a peculiar light gray color. Microscopic examination does not show any very marked metamorphism. Near the contact, however, the granitic rock is richer in lime (analysis 399, S. N.), which it may have absorbed (?) from the slates. The rock may also be regarded as a basic contact facies due to differentiation. In either case the above facts suggest that the granite is later in age than the Jurassic Mariposa slates. No. 399 was collected on Agua Fria Creek near the Mariposa slates, 5.2 km southwest of Mariposa. It is composed of micropegmatite, quartz, oligoclase, biotite, ilmenite, and epidote. Orthoclase is probably present although not determined in the thin section. Some of the epidote is wedged in between the other constituents all of which are fresh. This epidote is probably primary.

No. 413 is from the interior of the area above described, 6.5 km west of Mariposa. This was estimated to be a fair average sample of the rock. It is composed largely of albite and micro-

pegmatite, with less quartz, titanite, apatite, epidote, pyroxene, and uralite. A rough calculation shows that this rock is composed of about 64 per cent. of albite, 25 per cent. quartz, the remaining 11 per cent. including pyroxene, titanite, apatite, epidote and uralite. It is thus a true soda-granite.

South of the locality at which 399 was collected, on Agua Fria Creek, the soda-aplite is in sharp contact with granodiorite, but there was no satisfactory evidence found of the relative age of the two rocks. At the head of Owen's Creek, to the west of Cathay Valley, there is better evidence of the age of the soda-granite. The clay slates, which are pretty certainly of Juratrias age, are here clearly metamorphosed by the granitic rock.

In Butte and Plumas counties white dikes are abundant in metamorphic magnesian rocks, which are altered peridotites and pyroxenites. These dikes are mostly composed of quartz and albite, but in some muscovite is present. Analysis 725 is of a specimen collected from a dike in serpentine on Grizzly Hill in Plumas county. It is composed chiefly of spherulites of quartz and albite, micropegmatite, and abundant muscovite, the latter mineral chiefly in little rosettes. It has elsewhere[1] been suggested that these dikes of soda-granite and aplite are in some way genetically related to the peridotites and pyroxenites or other basic rocks with which they are usually associated.

*The aplite dikes in the gneisses and associated granites.*—In the bed of the North Mokelumne and other points there are irregular white dikes in the gneisses and associated granitic rocks. Some of these dikes are of evenly granular texture throughout, and may be called aplites; others are banded. A chemical analysis has been made of only one of these dikes, and this analysis taken in connection with the microscopical examination indicates that the rock is rich in soda, and hence the aplites in the gneisses are placed with the soda-aplites. It is by no means certain, however, that they are all alike in composition. Some of these dikes contain garnets. The aplites in the gneisses and

[1] Bidwell Bar folio of the Atlas of the U. S. Geol. Surv.

older granite are supposed to be older than the potash-aplites of the granodiorite series.

PARTIAL ANALYSIS OF SODA-APLITE (NO. 1830). ANALYST, STOKES

| | |
|---|---|
| $SiO_2$ | 76.17 |
| CaO | 1.64 |
| $K_2O$ | 2.48 |
| $Na_2O$ | 4.54 |

No. 1730 is a dike in gneiss from the north bank of the Mokelumne[1] a little below the mouth of Blue Creek in the Big Trees quadrangle. This rock is made up chiefly of quartz and feldspar. In addition there is a little biotite present. For the purpose, however, of a rough calculation this biotite can be ignored and all the lime ascribed to anorthite, all the soda to albite, and all the potash to orthoclase or microcline. Nearly all the alumina of the rock is contained in the feldspar molecules. The amount of alumina may therefore be calculated, and equals .1289 molecules, or by weight 13.15 per cent. The free silica can be estimated by deducting from the total silica the amount in the feldspar.

| | |
|---|---|
| Total silica | 1.2695 |
| Silica in feldspar | .6562 |
| Free silica | .6133 |

The molecular composition of soda-aplite No. 1730 is then approximately as follows.

| | Molecules | Percentage |
|---|---|---|
| Potash-feldspar | .2112 | 13.83 |
| Soda-feldspar | .5856 | 38.34 |
| Lime-feldspar | .1172 | 7.67 |
| Quartz | .6133 | 40.16 |
| | 1.5273 | 100. |

The albite and anorthite molecules together form plagioclase, the ratio being $Ab_5\ An_1$; hence the plagioclase is acid oligoclase. The potash-feldspar is chiefly or entirely microcline. The relative abundance of the constituents of soda-aplite No.

[1] See Seventeenth Ann. Rep. U. S. Geol. Surv., Part I, p. 700–705, for other notes about these gneisses.

1730 may be stated as follows: oligoclase > quartz > microcline > biotite.

*Quartz-diorite-aplite.*—In the bed of Bear River, Big Trees quadrangle, there are small white dikes from two to ten centimeters or more in width, occupying straight fissures in gneiss and quartz-diorite. The dikes have an aplitic texture and are much more acid than the quartz-diorite. It may be assumed that they bear a genetic relation to the diorite, similar to that existing between the potash-aplites hereafter described and the granodiorite and quartz-monzonite. In the table of analyses with the soda-granites there is given the chemical composition of one of these dikes (No. 1490) as well as that of the quartz-diorite (No. 1495) in which they occur. No. 1490[1] is practically an aplite, the feldspar, however, being probably chiefly andesine. The enclosing quartz-diorite is quite basic and we thus have a suggestion that the composition of aplitic dikes is determined by the composition of the granitic rock in which they occur. Rosenbusch[2] refers to tonalite-aplite and diorite-aplite and the dikes above described might be designated tonalite or quartz-diorite-aplite, following Rosenbusch. It should be noted, however, that by some authors the term aplite is restricted to granites composed chiefly of quartz and alkali-feldspar. If, however, dikes occur in various magmas which, while varying in composition, show a direct genetic relation to these magmas, some group term for such dikes is desirable.

*The potash-aplites and pegmatites of the granodiorite series.*—At a great number of points in the Sierra Nevada, there are dikes of a white rock from a few inches to a few feet in width. In the granodiorite and quartz-diorite these dikes are usually medium-grained with only occasional dark constituents. They grade over into pegmatite. The pegmatitic facies will, however, be treated in a later paragraph. This aplitic granite is composed of quartz > potash-feldspar > soda—lime-feldspar (oligoclase) > biotite > magnetite > apatite.

[1] Seventeenth Ann. Rep. U. S. Geol. Surv., Part I, p. 704.

[2] Mikroskopische Physiographie der massigen Gesteine, 1896, p. 464.

The chemical analysis given below shows more titanium oxide than is required for the biotite. Inasmuch as all the iron oxide is magnetic and therefore probably magnetite, it is likely that there is no ilmenite present. The remaining titanium oxide is therefore supposed to be present in titanite, which is the most common titanium mineral in the Sierra Nevada granites. This mineral was not, however, found in the thin sections. The relative proportions of these different minerals are taken from the calculation, as given below.

It is well known that as a general rule, the less siliceous elements crystallize out first and the more siliceous last in rock magmas. In most quartz-diorite and granitic magmas the alkali-feldspar and quartz are usually the last elements to crystallize, and they are, also, the most acid of the components of the rock. A possible explanation of the occurrence of aplite dikes in quartz-diorite and granitic magmas would appear to result from this law of crystallization. We have but to suppose that after the crystallization of the less siliceous constituents there is a residual mass of orthoclase and quartz in solution which is afterwards forced into fractures which form in the already consolidated granite, perhaps as the result of cooling. The laws of thermo-chemistry would appear to be applicable to such a scheme. Heat would be generated by the crystallization of the minerals of the granite and this heat would perhaps aid in establishing convection currents to transport the residual, more siliceous, constituents away from the already consolidated material. Moreover, as suggested by Dr. Hillebrand, the more siliceous material would be crowded away by the minerals which crystallize first, in the same way as the salt of sea water is crowded out by the crystallization of the water, so that the residual sea water, after a portion has crystallized or frozen, contains more salt, proportionately, than the sea water before crystallization began.

The following calculation of the relative molecular proportions of the various minerals found in the granodiorite-aplites is based on the average of two complete chemical analyses by Dr. Hillebrand, given in the table below. The calculation is

made in the same way as for the biotite-granite. The biotite in the aplites being similar to that of the biotite-granite, it is supposed to have the same chemical composition. The result of the computation is as follows.

COMPOSITION OF THE GRANODIORITE-APLITE

| | Molecules | Percentage |
|---|---|---|
| Quartz - - - - - | .6058 | 39.45 |
| Potash-feldspar - - | .4520 | 29.43 |
| Soda-feldspar - - - | .3536 | 23.03 |
| Lime-feldspar - - | .1008 | 6.56 |
| Biotite - - - - - | .0138 | .90 |
| Magnetite - - - | .0061 | .40 |
| Titanite - - - - - | .0027 | .18 |
| Apatite - - - | .0008 | .05 |
| | 1.5356 | 100.00 |
| Total molecules | 1.5523 | |
| Not accounted for | .0167 | |

ANALYSES OF POTASH APLITES

| | 159 Nevada city | No. 227 S. N. | No. 161 S. N. | Average of 227 and 161 | Molecular proportions of the average |
|---|---|---|---|---|---|
| $SiO_2$ | 77.05 [1] | 75.97 [2] | 76.03 [2] | 76.00 | 1.2667 |
| $TiO_2$ | ......... | .09 | .07 | .08 | .0010 |
| $Al_2O_3$ | ......... | 13.07 | 13.39 | 13.23 | .1297 |
| $Cr_2O_3$ | ......... | none | ............ | ............ | ......... |
| $Fe_2O_3$ | ......... | .61 | .48 | .54 | .0034 |
| FeO | ......... | .39 | .31 | .35 | .0049 |
| MnO | ......... | trace | trace | trace | ......... |
| NiO | ......... | none | ............ | ............ | ......... |
| CaO | .73 | 1.49 | 1.28 | 1.38 | |
| SrO | ......... | .03 | trace | .02 } 1.49 | .0266 |
| BaO | ......... | .14 | .04 | .09 | |
| MgO | ......... | .14 | .05 | .09 | .0022 |
| $K_2O$ | 5.06 | 5.62 | 5.18 | 5.40 | .0574 |
| $Na_2O$ | 3.43 | 2.51 | 2.98 | 2.74 | .0442 |
| $Li_2O$ | ......... | trace | none | ............ | ......... |
| $H_2O$ below 110° C. | ......... | .14 | .15 | .14 | ......... |
| $H_2O$ above 110° C. | ......... | .24 | .34 | .29 | .0161 |
| $P_2O_5$ | ......... | trace | .03 | .02 | .00014 |
| $CO_2$ | ......... | none | ............ | ............ | ......... |
| Total | | 100.44 | 100.33 | 100.37 | 1.5523 |

Analyst: [1] Stokes. [2] Hillebrand.

159, N. C. is taken from Lindgren's paper in the Seventeenth Ann. Rep., U. S. Geol. Surv., Part 2, p. 45.

227, S. N. Dike in quartz-mica-diorite (No. 225, S. N.) about 3.2 km. east of Milton in the Downieville quadrangle The dike is about 60 cm. wide.

171, S. N. Dike in the quartz-mica-diorite about 11 km. east of the Sierra Buttes, Downieville quadrangle. The dike is quite wide and is intersected by joints, the most prominent set being nearly vertical.

*Pegmatites.*—The pegmatites which are associated with granodiorite and quartz-monzonite are very often banded, the border

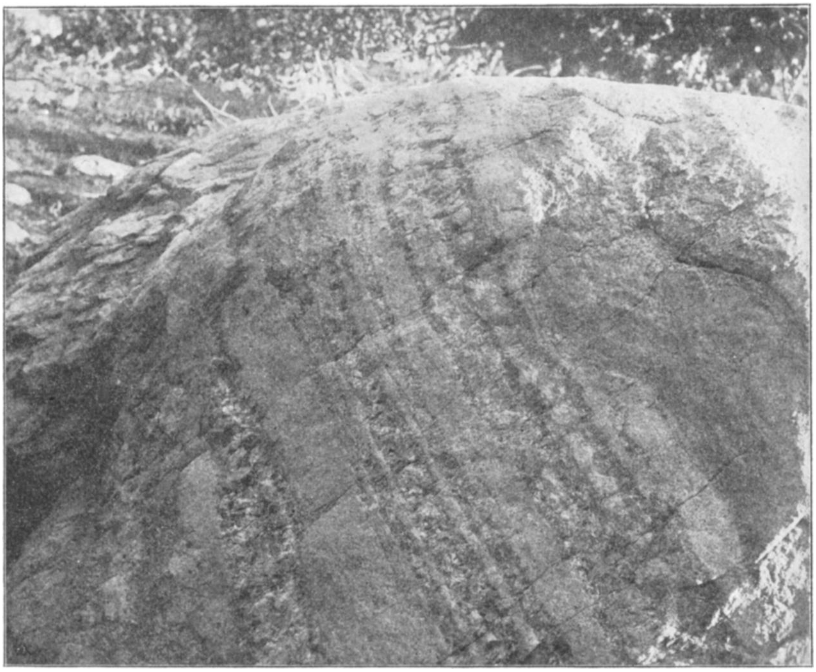

FIG. 1.—Boulder of aplite-pegmatite on ridge south of Highland Creek in the Big Trees quadrangle.

of the dike being aplite and the middle layer pegmatite, thus forming a suggestion of the "comb" structure shown in some quartz veins. In certain cases the banding is repeated, there being several layers of aplite with pegmatite between. This is

shown in Fig. 1. In the more acid dikes or veins (?) the middle band is quartz with aplite borders.

It is not yet ascertained whether the aplites and pegmatites occurring in the different granites of the Sierra Nevada show characteristic differences that are constant. The oligoclase-aplite (No. 1730), previously described as coming from the North Mokelumne River, was presumed in the field to be typical of the aplites of the gneisses and biotite-granite; but it remains to be shown if there is not considerable diversity in these dikes. There are, for example, in the Yosemite quadrangle, in biotite-granite, sporadic bunches of white platy quartz interspersed with chunks of flesh-colored orthoclase or microcline. This forms practically a coarse pegmatite. The quartz in these bunches greatly exceeds in amount the potash-feldspar so far as my observation goes. One bunch of white quartz by the trail to the "Fissures" south of Yosemite Valley is 18 meters long and 14 wide, with chunks of potash-feldspar; but nine tenths of the mass is quartz. Some of the pegmatite in biotite-granite is distinctly banded,[1] the same as in granodiorite.

H. W. Turner.

[1] Seventeenth Ann. Rep., U. S. Geol. Surv., Part I, p. 700, Plate XXXIV.